Naval Aerospace Medical Research Laboratory

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THE DEVELOPMENT AND INITIAL VALIDATION OF THE UNMANNED AERIAL VEHICLE (UAV) EXTERNAL PILOT SELECTION SYSTEM

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ABSTRACT

The purpose of this study was to develop physical and selection performance standards for the screening of candidates for entrance into the Unmanned Aerial Vehicle (UAV) Pioneer Pilot training program. A minimum Pioneer crew consists of an external pilot, internal pilot, and a mission commander/payload specialist. The mission commander/payload specialist is responsible for the overall planning and execution of the specific mission and control of the visual/information gathering during the mission. The internal pilot is responsible for the control of the Pioneer when it is beyond visual range. The external pilot is responsible for take-offs, landings, and any in-visual-range control of the vehicle. A task analysis was done in the training and fleet squadrons to identify critical tasks for safe flight and the relevant skills required to perform the piloting tasks. From this task analysis, specific computer-based tests batteries were chosen as potential predictor variables. The system was programmed and students and external pilots were administered the test battery. A composite training measure was created from objective training scores, verified with subjective instructor ratings, and used as the criterion for predictive validation of the system. The sample size was small for the preliminary model, but a significant relationship between a composite of multitask tracking scores and UAV performance was observed (adjusted $R^2 = 0.86$). In addition, structured and unstructured interviews of the Pioneer crews, students, instructors and senior squadron personnel were used to identify important physical characteristics essential for safe operation of the Pioneer. These traits were then used to derive medical screening criteria for all crew positions.

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INTRODUCTION

Unmanned Aerial Vehicles (UAVs) are remotely piloted vehicles (RPVs) currently used by the U.S. Navy, Marine Corps, Army, and Air Force for airborne reconnaissance, surveillance, target acquisition, fire support adjustment, and battle damage assessment. The U.S. Army and Air Force are currently involved with the test and evaluation of a number of larger UAV systems such as the Predator and Hunter systems. These systems can remain airborne for long periods of time, have high altitude capabilities, and carry relatively heavy payloads. They also require lengthy runways for take off and landing and larger support/maintenance crews for operation. The Navy, due to its unique operational environment, is currently using the smaller Pioneer UAV for RPV support in the field. The Pioneer is a relatively small air vehicle with a wing span of 16.9 ft, a length of 14 ft, and a height of 3.3 ft and is capable of providing information to amphibious forces without over-taxing a ship's storage capacity and/or necessitating the removal of other airborne and warfighting assets aboard ship. For shipboard operations, the Pioneer can be launched directly from a stand (called a rocket assisted take off or RATO) from the deck of the ship and can be recovered by a catch net on the bow of the ship. These nets are suitable for both daytime and nighttime operations. This method of launch and recovery obviates the need for carrier decks for this vehicle. The portable/mobile Pioneer systems can also be used in the field to support deployed Marine Corps units, or launched from a general purpose amphibious assault ship and 'passed' off to portable field units for reconnaissance. Field take offs and landing require as little as 21 meters for pneumatic launches and 70 meters for recovery.

The Pioneer contains an expensive electronics package and surveillance equipment, with the total airborne system costing in excess of $800,000. The Pioneer can relay video and/or telemetry information in real time to a ground control station and/or portable control units for deployed forces. Its service ceiling is 12,000 ft, with a cruising speed of 65 kts and a maximum range of 185 km. With its low radar cross-section, low infrared signature, and remote control versatility, the system is ideal for unmanned battle damage assessment and search and rescue operations in hostile areas. The Pioneer system and crews were successfully deployed and used in support of operations during the Gulf War.

The minimum personnel requirements for operation of the Pioneer is a three person crew: an external pilot (EP), an internal pilot (IP), and a mission commander/payload operator. Some operations may also include an intelligence officer as a crew member. The primary responsibility of the IP is flight control of the aircraft using only instrumentation when the craft is beyond visual range and performing its mission. Most of this flying is done on autopilot. When in visual range, and during take-offs and landings, the aircraft control is handed off to the EP while the IP feeds him/her aircraft speed, heading and altitude information. Both the IP and EP positions are held by petty officers or noncommissioned officers with prior aviation-related experience (i.e., maintenance technicians, etc.). The mission commander is responsible for the overall safety and success of the mission, and the payload operator controls the visual sensors during flight. Mission commanders are most often officers with prior aviation experience. All mission commanders must be IP qualified. In addition to their primary duties, all crew members are responsible for system assembly and breakdown, and minor maintenance and repair of the aircraft when it is deployed. All crew members receive their initial training at the Department of Defense UAV Training Center (DUTC). This initial training includes, at a minimum, a ground syllabus on systems, basic operations, and procedures of the Pioneer, as well as actual flight training with simple RPVs, scaled-down versions of the Pioneer, and then the actual Pioneer system. Despite the complex psychomotor, cognitive, and perceptual skills required to control this aircraft, no a priori selection (medical or performance-based) criteria were established for entry into this training curriculum.

The EP initial program includes an extensive 18-week syllabus, with a week of ground school and then flight training for the remainder of the syllabus. Following completion of DUTC training, graduates are sent to either a Marine Corps unit or a Navy squadron detachment for further hands-on training before deployment with operational forces. In the past, students who were marginal performers at DUTC were given extended training (up to 22 weeks) to meet minimum accepted standards before to being sent to their units. On occasion, the field units have found that these students arrive without all of the requisite skills/abilities to be safely deployed to the high-stress, highly demanding operational environment. In addition, recent mishaps that included the complete loss of

the aircraft due to human error led to the decision by the Navy's UAV community to try and improve the caliber of applicants who enter training and, thereby, reduce training costs and maintain the quality of the pilots in the fleet.

The Naval Aerospace Medical Research Laboratory (NAMRL) was tasked by Naval Air Systems Command (NAVAIR) to develope a performance-based selection system for predicting which UAV EP candidates have the greatest probability of (1) completing UAV EP training, (2) completing UAV EP training within a shorter time period, and/or (3) demonstrating higher proficiency in performance of EP tasks following training. An additional tasking from NAVAIR was to enlist the aid of the Aeromedical Advisory Council at the Naval Operational Medicine Institute (NOMI) to develop medical standards/qualifications for UAV EPs and IPs. The need for screening medical standards was evident in a number of cases where individuals without the physical means (i.e., grip strength problems, night blindness, etc.) to complete training were nonetheless sent to DUTC for the 18-week syllabus. Due to the small size of this community, any delay attrition from training severely limits the capability of the fleet squadrons to meet their operational requirements.

METHODS

The methods used to develop and validate the UAV selection system and medical standards included field observations, expert and student interviews, curriculum reviews, and standard testing and psychometric evaluation of the test battery scores and criterion data.

SUBJECTS

During the task-analysis phase of the study, currently qualified and student EPs, IPs, and Mission Commander/payload operators were observed and interviewed for critical phases of flight and the essential skills/physical abilities needed to perform their jobs. Instructors and senior squadron personnel (OICs, Safety Officers, etc.) were also interviewed. These observations were made at the initial training site at DUTC in Ft. Huachuca, Arizona, at VC-6 detachment at Patuxtant River, Maryland, and at VMU 1 at 29 Palms, California. For the system validation portion of the study, eight student EPs were tested at DUTC, and six current EP/IPs were tested at VC-6 detachment. All participants were right-handed males; the overall average age was 29.57 (SD = 5.24). The average age for the students was 27.5 (SD = 4.72), and the average age of the pilots was 31.17 (SD = 5.91).

APPARATUS

The Computer-based Performance Test (CBPT) is a 2-h test battery that measures eye-hand-foot coordination (multitasking), spatial/mental ability, divided auditory attention, and cognitive skills. Similar to a video game run on an IBM- or PC-compatible computer (386/25 MHZ or greater), the system requires a VGA monitor, two joysticks, rudder pedals, numeric keypad, and headphones. The CBPT has several programmed test batteries that are predictors of student naval aviator and naval flight officer performance and attrition (Delaney, 1992; Street, Chapman, & Helton, 1993). The system has also been used for the Landing Craft Air Cushion Vehicle operators and engineer position training outcome (Dolgin & Nontasak, 1990; Nontasak, Dolgin, Blower, 1991; Robertson & Nontasak, 1996). In addition, one new test was created and programmed for this project.

PROCEDURE

Critical tasks for the safe operation of UAVs in the operational environment were identified through structured and unstructured interviews with instructors, EPs, and IPs, as well as observations of actual flight training and field operations using the Pioneer. The identified critical tasks were analyzed for the required behavioral skills and minimum physical standards. Subtests from the CBPT that measure these identified skills were chosen as potential predictors and included in the test battery. Criterion measures were identified via curriculum reviews and instructor interviews.

Critical Task and Task Analysis: Performance

Analysis of Pioneer field operations highlighted the importance of a few critical time periods during flight. Barring a systems failure, instrument control by the IP is adequate to maintain safe flight when the craft is outside of visual range. In visual range, critical junctures occur during the transfer of control (IP to EP), following wave-offs when control reversals occur, and during landings. For example, during shipboard landings, the Pioneer is targeted to the center of a vertical net located on the ship. The target zone is a section of net approximately 60 x 20 ft. For night missions, these captures are accomplished by darkening the lights on the flight deck and illuminating the central portion of the net. The EP then estimates aircraft distance and direction from the net by the relative location and distance between the port and starboard lights on the aircraft wings. Typically, EPs place an earcup on one ear and leave the other ear uncovered during this and all other in-visual-range tasks. This enables them to attend simultaneously to the heading and airspeed calls of the IP, as well as to the shipboard sounds/environment. Although the Marine Corps' operational environment differs from that of the Navy, a similar method of one ear covered, one uncovered has been adopted to maintain situational awareness. In addition, the Marines experience the same critical junctures during IP to EP transfer, control reversals during aborted landings/fly-bys, and nighttime arrested landings. The tasks/skills necessary for EPs to successfully complete these maneuvers include mental reversals/rotation, time estimation to contact for the approaching aircraft, hand-eye coordination, selective auditory attention, and multitasking (psychomotor and visual components). For the IP, mission commander, and payload operator, no critical skills or problem areas were apparent nor seemed to be relevant for screening purposes. In addition, IP training is only a 2-month curriculum, and preventable mishaps and difficulties with personnel at the fleet level have focused on the EP position.

The following tasks were chosen for the experimental test battery due to their correspondence with the above-mentioned skills. The battery consists of three major categories:

1. Psychomotor (PMT) and Dichotic Listening (DLT) Tests
2. Horizontal Tracking (HT) and Digit Cancellation (DC) Tests
3. Manikin and Time Estimation Task (TET) Tests

1. PMT and DLT Tests. The subtasks within this test, and the order in which they were administered, are listed below:

A. Stick Task: The subjects use the joystick (referred to as the stick) directly in front of them to control the green, middle cursor (shaped like a cross "+") on the screen. The object of the task is to maintain the cursor at the center of the screen where the vertical and horizontal rows of dots intersect (see Figure 1). Movement of the stick causes the cursor to move in the opposite direction, and the natural drift of the cursor (if the stick is released) is toward the upper right-hand corner of the screen. The subjects have one 3-min practice session, followed by a brief pause before the actual scored test starts.

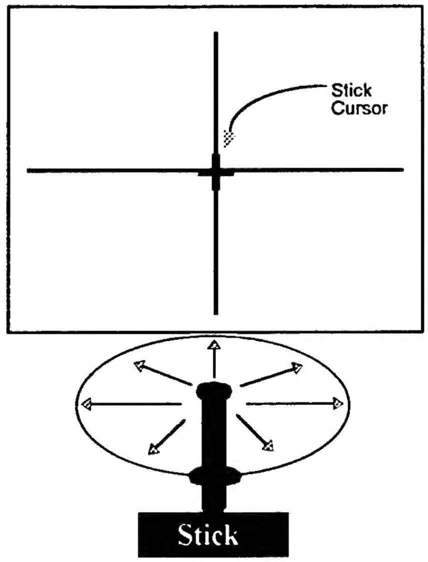


Figure 1. PMT: Stick Task.
(cursor at zero error position)

B. DLT Task: In this test, the subjects are presented a unique string of numbers and letters to each ear simultaneously. The computer specifies which ear to pay attention to ("RIGHT" or "LEFT"). Using their left hand, the subjects key in only the numbers heard in the designated ear while ignoring the letters. The DLT consists of 12 trials. In each trial, the subjects receive two different streams of information with a pause between them. The first stream contains five numbers mixed with letters. The second stream contains four numbers, also mixed with letters. An example of a DLT trial is illustrated in Table 1. In this table, the Left and Right Ear Stimulus columns represent the spoken messages that the subject hears in each ear. The rows of the table represent the sequence in time.

Table 1. DLT Trial Visual Example.

Sequence	Left Ear Stimulus	Right Ear Stimulus
Trial #	"Test 1"	"Test 1"
Attention	"RIGHT"	"RIGHT"
Stimuli	"R 8 N S M Y 2 G B 7 F L 6 R L 5"	"Y L **3** S R **4** F Z **9** X F **0** F N **1** L"
Pause		
Attention	"LEFT"	"LEFT"
Stimuli	"B F **4 3 7 9**"	"G L 1 5 6 2"

Because subjects often find the DLT difficult to initially comprehend, they are given four practice sessions before beginning the actual test. Both the correct responses and the subjects' responses appear on the screen after each practice session.

C. Stick & DLT Task: In this test, subjects combine the STICK and DLT tasks. The stick tracking task is performed with the right hand grasping the stick, and the DLT responses are keyed in with the left hand on the numeric keypad. This task has no DLT practice sessions. The DLT begins after about 15 seconds into the tracking task, and 12 trials are presented. After the last DLT trial, the subject continues the tracking task until the session terminates.

D. Stick & Rudder Task: The subject performs the rudder (the pedals) task and the stick task simultaneously. The rudder cursor moves side to side. The task is to use the rudder pedals to hold the cursor on the vertical line (on the lower left center of the screen) while maintaining the other cursor on the appropriate target. The cursor moves back and forth in the same direction as the rudder movement.

E. Stick, Rudder, and DLT Task: The participant performs the stick, rudder, and DLT tasks simultaneously. Subjects perform DLT inputs are made with the left hand.

F. Stick, Rudder, and Throttle Task: The participant performs the throttle (the joystick to the left), stick, and rudder tasks simultaneously. The red throttle cursor moves up and down. The task is to use the left hand to hold the throttle joystick to keep the cursor on the horizontal line (on the left side of the screen) while maintaining the other cursors on the appropriate targets. The left cursor moves up and down in the same direction as the throttle movement. Figure 2 depicts the cursors at the zero-error position for this task. These combined tasks have all been found to be good models of multi-tasking/high task loads and correspond to the multitasking situations encountered routinely by EPs.

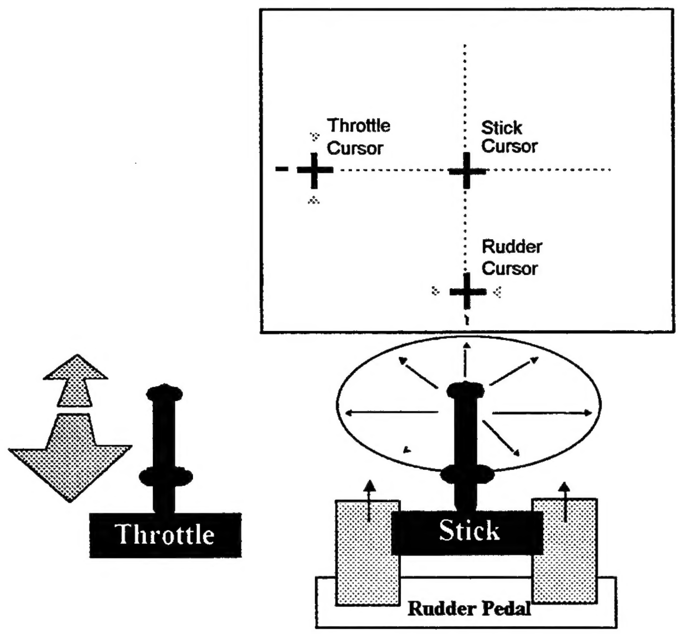


Figure 2. PMT: Stick, Rudder, and Throttle Task.

Table 2 illustrates the sequence and duration of the tests that make up the PMT/DLT portion of the test battery. Generally, 1 hour is needed to complete all PMT/DLT activities. The PMT/DLT tests were chosen for the experimental battery due to their correspondence with the hand/eye coordination and multitasking/workload requirements of the EP, as well as their mode of communication in operational environments (one ear covered, one uncovered).

Table 2. PMT/DLT Test Duration.

Test	Trial	Time (min)	Cumulative (min)
1. Stick	Practice	3	3
	Scored	3	6
2. DLT	Practice	3	9
	Scored	4	13
3. Stick/DLT Dual	Scored	4	17
4. Stick & Rudder	Practice	3	20
	1st Scored	3	23
	2nd Scored	3	26
5. Triple (stick, rudder, DLT)	Scored	4	30
6. Throttle (with stick, and rudder)	Practice	3	33
	1st Scored	3	36
	2nd Scored	3	39

2. The HT and DC Tests.

A. HT Task: This portion of the test requires subjects to keep a square cursor centered in a rectangle (see Fig. 3). The cursor is driven by a computer-programmed forcing function that accelerates as the distance from the centerpoint increases. Controlling the stick with their right hand, subjects make appropriate counterbalance movements of the cursor. The cursor moves in the same direction as the movement of the stick. To perform well on this task requires minute inputs and constant adjustments to 'balance' the cursor on the centerpoint. The subjects work through seven of these sessions.

B. DC Task: This task requires subjects to use their left hand to key in numbers 1-4 on a keypad as they appear on the screen. The DC task is used primarily as a distractor.

C. HT/DC Task: This final portion of the test requires subjects to perform the horizontal tracking and digit cancellation tasks at the same time. The subjects must pay equal attention to each task. The numbers for the DC task are centered at the top of the HT rectangle. The subjects work through three sessions. Again, the DC is performed with the left hand and the HT with the right hand.

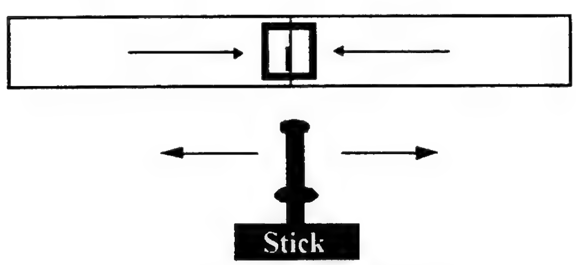


Figure 3. Horizontal Tracking.
(cursor at zero position)

The length of the HT, DC, and Dual HT/DC tasks is included in Table 3. The HT/DC tests measure more fine motor control ability with a distractor task and correspond to the multi-tasking and fine motor controls required in EP flight operations.

Table 3. HT/DC Test Duration

Test	Time (min)	Cumulative (min)
1. Horizontal Tracking	15	15
2. Digit Cancellation	2	17
3. Dual HT/DC	8	25

3. The Manikin and Time Estimation Task Tests.

A. The Manikin Test: The Manikin test is a test of visuospatial abilities, consisting of 48 drawings of a sailor holding a square in one hand and a circle in the other. The sailor is depicted either right-side up or upside down, facing toward or away from the subject. The objective is to determine as quickly as possible which hand is holding the square. The Manikin test is not timed. This test, in its most basic form, measures the ability to perform mental rotations/reversals and was chosen for being relevant to the EP control reversals during fly-bys.

B. The Time Estimation Task (TET) Test: The TET is a test of visual tracking and time estimation abilities. The subject's task is to track a moving target (an aircraft) as it moves at a constant rate across the screen. It is visible brifely after appearing on the screen and then disappears. The goal of the subject is to accurately predict (by pressing the joystick trigger) when the aircraft should appear above the target. When the subject presses the trigger, the aircraft reappears on the screen, and the mean pixel error is recorded. The speed of the aircraft varies from trial to trial, but the initial visible view of the aircraft remains constant throughout the test. In addition to the TET, the aforementioned HT task is included as a distractor with this test. Thus, the subject must maintain the cursor on the center point with the joystick while firing the joystick trigger at the appropriate time. The TET was specifically created for this test battery. The task measures time/distance estimation abilities which are essential to the EPs' control of the Pioneer.

Critical Task and Task Analysis: Physical Standards:

The need to adopt more rigorous physical standards for entry into the Pioneer community was evident in the above-mentioned training problems, as well as the JAN 95 Class B UAV mishap report that cited poor visual acuity of an EP as a causal factor (U.S. Navy Message Traffic, 1994). Under ideal conditions, many physical limitations of UAV crew members may have no impact on safe and effective mission performance. On the other hand, the fleet and field environments under which they have to operate can be extreme in both climate and operational pace. For this study, the Chairperson of the NOMI Aeromedical Advisory Council took an approach that was similar to that used for the development of the Landing Craft Air Cushion Vehicle crew member standards (Hunt, Linnville, Stuster, Schneider, & Braun, 1993). First, the type of work being performed and the environmental conditions of Pioneer operations were established. This was done via discussions with flight surgeons and aeromedical personnel involved in recent UAV mishap investigations and site visits to observe the operations at VC-6 and VMU-1. Secondly, the goal was to develop a hypothesis of significant aeromedical factors involved in these tasks (i.e., visual acuity, hearing loss, etc.). This was done in coordination with some interim standards that had been developed by the U.S. Marines to deal with aeromedical issues in the field. Lastly, structured interviews with squadron and unit personnel were used to test the hypothesized elements, establish their relevance, and make formal recommendations to the Aeromedical Advisory Council.

The applicable physical standard elements by position can be seen in Table 4. As would be expected, communication (both speech and audition) and visual factors are important for all positions, but most critical for EPs. Given that a large percentage of Pioneer flights are at night and EPs have to guide the craft in using only wing tip and tail lights of the craft, color and good night vision are essential. Because of the importance of good visual acuity, the recommendation was that EPs should also receive training on factors that can influence acuity. The final guidelines and recommendations made by the Aeromedical Advisory Council were to use the existing physical examination standards that are used for Navy and Marine Corps air traffic controllers with an additional

requirement of depth perception testing for EPs.

Table 4. Applicability of Physical Standard Elements by Function.

Task	External Pilot	Internal Pilot	Payload Operator	Mission Commander	Notes
Night vision	X	X		X	External wingtip lights; only cue during rolling T/O
Color vision	X	X		X	Rolling T/O; interpretation of turns; console warning lights
Depth perception	X			X	Operator 75-90 ft from net; mid runway for rolling recovery
Distant vision	X			X	
Near vision	X	X	X	X	
Peripheral vision	X	X	X	X	
Accommodation	X			X	Checking control box switches
Hearing	X	X	X	X	MC role >75% hearing based
Clear speech	X	X	X	X	Reading Aloud Test
Stress coping/AA	X	X		X	USMC: Multiple taskings; USN: Changing operator/ maint roles
Medication use					Any affecting vision, hearing, balance, alertness, or judgment
Motion sickness			X		Simulator sickness/ship; IP/PO have no external references
Physical training	X			X	Visual illusions especially at night; fatigue/nutrition

Statistical Analysis

Log-transformed error scores (cumulative number of pixels from the center of the screen) were used as the dependent measure on all CBPT tracking tasks (see Appendix A for tasks and dependent measures). Number correct and reaction times for correct responses were used on the Manikin and DC tasks, and the total number of correct responses across trials was analyzed for the DLT.

Factor analysis was used to develop a single composite predictor score, and this score was regressed on a criterion reflecting overall training performance. The final step, after choosing the best regression equation, was to locate a cut-off score to be used by the prediction algorithm. The prediction algorithm serves to classify a candidate who desires to enter UAV training as either a predicted PASS or a predicted FAIL based on his performance on the CBPT. All analyses were done using SPSS 6.1.

RESULTS

PREDICTORS CHOSEN

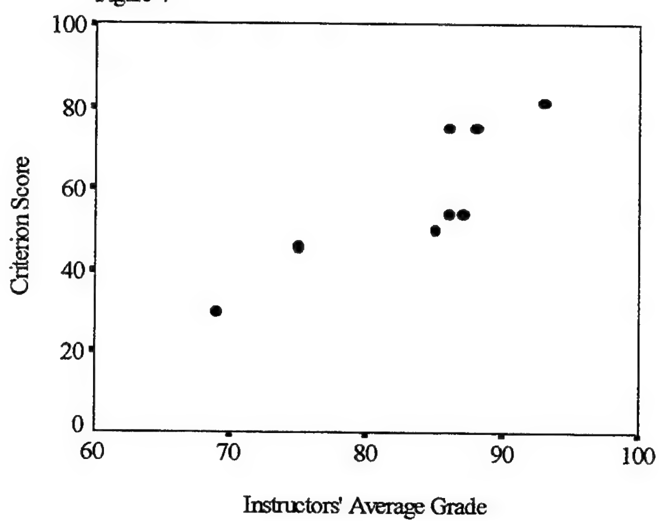
The original data from the CBPT consisted of 63 raw scores, from which 8 scores were derived to capture the essence of the CBPT tasks (see Appendix B). The derived scores represented psychomotor performance on (1) stick only (S); (2) DLT only (D); (3) stick combined with DLT (SDLT); (4) stick and rudder (SR); (5) stick and rudder combined with DLT (SRDLT); (6) stick, rudder, and throttle (SRT); (7) horizontal tracking with digit cancellation (HTDC); and (8) spatial rotation (MANIKIN). A factor analysis was performed on the eight derived scores, and only those factors with eigenvalues greater than 1.00 were retained. Four factors were retained using this criterion. When various regression equations were evaluated using the factor scores from the four factors as independent variables, the most parsimonious model included just the first factor. Therefore, a single predictor variable--a linear combination of the eight derived psychomotor variables--was retained in the algorithm to predict student success. The weights assigned to each derived score are the weights that are used to construct the first

weights are explicitly shown below in the section Prediction Algorithm.

CRITERION MEASURES

The criterion measures were identified from the biweekly instructor evaluation sheets and the actual flight data. A criterion score between 0 and 100 was assigned to each of the trainees, with a higher criterion score representing better performance in training. Instructors were also asked to provide subjective overall ratings of the participants on the same scale. The ratings were averaged across instructors for corroboration of the more objective scaling obtained from the flight data sheets. The ratings between the two methods were highly correlated (see Fig. 4).

Figure 4

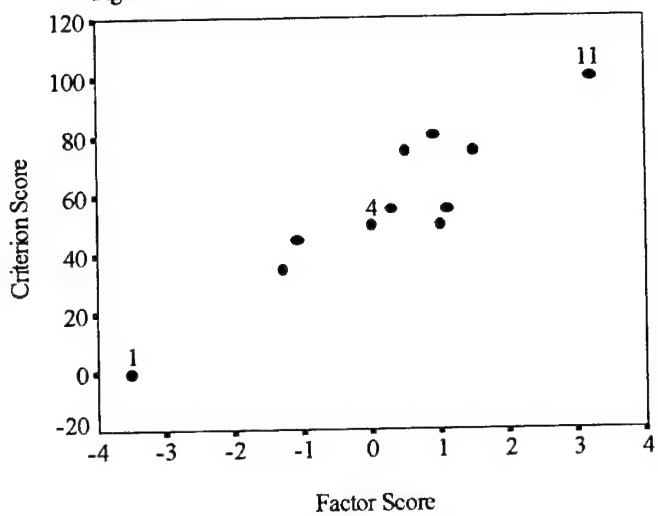


LINEAR REGRESSION

As mentioned previously, a number of linear regressions were carried out on these data with either one, two, three, or four factor scores used as independent variables and the criterion score as the dependent variable. When the R^2 from the linear regression was penalized for including extra independent variables, the regression using the first factor score was singled out as having the highest adjusted R^2.

Criterion data were available on only eight external pilot participants, so three "mock" data points were inserted into the regression in an attempt to improve the predictive algorithm. Three fictitious data points were calculated for criterion scores at 0, 50, and 100 to represent worst, mediocre, and best training performance, respectively. This attempt to anchor the end points of the model (i.e., extremely bad test performance and extremely good test performance) is similar to the "mixed estimation" technique (Belsley, 1991) used to improve linear regression models. See Fig. 5 for a plot of the first factor score versus the criterion score for these 11 data points (i.e., 8 experimental participants and 3 mock data points). The experimental participants are shown as circles in the figure, and the mock data points have the numbers 1, 4, and 11 above them. The adjusted R^2 for the linear regression through these points was 0.86. A linear combination of the eight derived psychomotor variables predicted a high proportion of the variance in UAV training performance.

Figure 5



PREDICTION ALGORITHM

The end product of this research effort is a single algorithm for predicting whether a candidate is likely to pass or fail UAV training. The final step in accomplishing this goal is the selection of a threshold score.

Determining such a cut-off score depends on many factors that must be made by the training community itself. Therefore, we queried the UAV instructors and our own data for a grade that represented the minimum acceptable performance for transition to a fleet assignment. The UAV instructors chose a grade of 80 as indicating minimal acceptable performance. This meant that two of the experimental participants were not performing adequately during training. The instructors' cut-off score corresponded to a criterion score of 50, which, in turn, corresponds to a factor score of 0. Simply put, this allows the prediction algorithm to be stated as: if the factor score for a candidate > 0, then predict PASS.

In detail, this is calculated as follows. The predictor variable (or first factor score) is computed as:

$$\text{Predictor variable} = .1866z_1 + .01735z_2 + .29152z_3 - .27195z_4 + .26090z_5 - .25766z_6 + .18618z_7 - .21437z_8$$

This is a linear combination of z scores for the eight derived measures. Negative weightings on z_4, z_6, and z_8 (S, SR, and SRT, respectively) are due to the fact that a higher tracking score is correlated with poorer performance and vice versa. The following is the variable assignment corresponding to the above equation: z_1 = D; z_2 = HTDC; z_3 = MANIKIN; z_4 = S; z_5 = SDLT; z_6 = SR; z_7 = SRDLT; and z_8 = SRT. After the value of the predictor variable has been calculated, the prediction algorithm can be invoked. If the predictor variable ≤ 0, then predict FAIL, otherwise predict PASS.

This predictor variable is simply a factor score, and factor scores are defined as linear combinations of z scores. For each individual candidate in which a prediction is desired, a z score on each of the eight tests is computed. Each z score gives the relative standing of that individual for each of the eight tests. These z scores are then weighted according to the above equation. For each individual candidate, the z score for the i^{th} test is computed by taking the candidate's score on the i^{th} test, subtracting the estimate of the overall mean for that test and then dividing by the estimate of the standard deviation of the i^{th} test.

In symbols:

$$Z_i = \frac{X_i - \overline{X}_i}{SD_i}$$

DISCUSSION

The DUTC training program currently trains about 12 EPs annually, which was the reason for the limited sample size in this study. Even so, we found a strong association between the tests in this battery and training performance. In fact, compared to other operational systems developed at NAMRL, this system has shown the strongest initial relationship with training outcome. The tracking/multitask tests were found to be predictive of both objective and subjective measures of success in the UAV EP training program, and these test were all included in the final predictive algorithm. Their inclusion was not that surprising because the tracking plus dichotic listening test is very similar to the real-world control/divided attention task required of Pioneer EPs during Navy shipboard and Marine Corps field operations. The Manikin test was also found to be predictive of performance. Although it is not a 'pure' mental rotation test since it can be solved through alternate means (i.e., matching-to-sample, categorization, etc.), it has been useful in this laboratory in predicting success in diverse curricula such as LCAC navigator training and the Navy's primary pilot training syllabus.

The TET is the only multitask test that was unrelated to training performance for the EPs. It was specifically developed to measure the ability to judge time/distance information that is presumably important for an EP during approaches and departures. Thus far, the task has failed to predict individual differences in training performance. We are currently evaluating the usefulness of the TET as a predictor for other aviation populations.

Our conclusions from the CBPT data are preliminary but promising for the operational use of this system. The initial algorithms developed from this work have been programmed into the screening system. Screening of UAV EP candidates at NAMRL is planned for the next few years, and the data will be used for continued validation of the system. In addition to the items included in the experimental battery, a new task (i.e., three-dimensional reversal) that may be relevant to training performance will be added to the system. As more individuals are screened and criterion data become available, the model will be refined and a final system developed for transition to operational use.

The medical standard recommendations from this study have been approved by the U.S. Navy Bureau of Medicine and Surgery (BUMED) and are to be incorporated into the new version of the Manual of the Medical Department (MANMED). The standards to be used for the EP position are the same as those used for air traffic controllers, with an additional requirement for color vision and depth-perception screening. As with the air traffic controller community, medical consultation is necessary before resuming flight operations when ill or on medications.

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APPENDIX A. Psychomotor Task and Dependent Measures

TASK	SPECIFIC ABILITY	DEPENDENT MEASURE
Performance Test One		
Stick Only	eye-hand coordination	accumulated pixel errors over test duration
Dichotic Listening	divided attention	number correct
Stick/Dichotic Listening	eye-hand coordination and divided attention	accumulated pixel errors over test duration and number correct
Stick/Rudder	eye-hand-foot coordination	accumulated pixel errors over test duration
Stick/Rudder/Dichotic Listening	eye-hand-foot coordination and divided attention	accumulated pixel errors over test duration and number correct
Stick/Rudder/Throttle	eye-hand-foot coordination	accumulated pixel errors over test duration
Performance Test Two		
Horizontal Tracking (HT)	two-dimensional tracking	accumulated pixel errors over test duration
Digit Cancellation (DC)	reaction time and short-term memory	number correct and reaction time
HT/Digit Cancellation	time sharing, two-dimensional tracking	accumulated pixel errors over test duration
Performance Test Three		
Manikin	mental rotation and short-term memory	number correct and reaction time
Time Estimation Task (TET)	two-dimensional tracking	accumulated pixel errors over test duration

Appendix B. Eight Derived Psychomotor Scores

$$S = \log_{10}(STICK) \tag{1}$$

$$D = \frac{DLT}{4} \tag{2}$$

$$SDLT = \frac{DLT\_STK}{\log_{10}(STICKDLT)} \tag{3}$$

$$SR = \sqrt{\log_{10}(ST\_RDR) \times \log_{10}(RDR\_ST)} \tag{4}$$

$$SRDLT = \frac{DLT\_STRD}{\sqrt{\log_{10}(SRD\_DLT) \times \log_{10}(RDS\_DLT)}} \tag{5}$$

$$SRT = \sqrt[3]{\log_{10}(SRT\_STK) \times \log_{10}(SRT\_RDR) \times \log_{10}(SRT\_T)} \tag{6}$$

$$HTDC = \left(\frac{HTDCC1}{\log_{10}(HTDC1)} + \frac{HTDCC2}{\log_{10}(HTDC2)} + \frac{HTDCC3}{\log_{10}(HTDC3)}\right)/3 \tag{7}$$

$$MANIKIN = \frac{x}{4} \tag{8}$$

$$\begin{aligned} x &= (MN1\_COR - MN1\_INC) + (MN2\_COR - MN2\_INC) \\ &\quad + (MN3\_COR - MN3\_INC) + (MN4\_COR - MN4\_INC) \end{aligned}$$

(1) STICK = STICK error score.

(2) DLT = Number correct in Dichotic Listening Test.

(3) DLT_STK = Number correct in Dichotic Listening Test when done in conjunction with STICK tracking.
STICKDLT = Stick error score when done in conjunction with Dichotic Listening Test.

(4) ST_RDR = STICK error score when done in conjunction with RUDDER tracking.
RDR_ST = RUDDER error score when done in conjunction with STICK tracking.

(5) DLT_STRD = Number correct in Dichotic Listening Test when done in conjunction with STICK and RUDDER tracking.
SRD_DLT = STICK error score when done in conjunction with DLT and RUDDER tracking.
RDS_DLT = RUDDER error score when done in conjunction with DLT and STICK tracking.

(6) SRT_STK = STICK error score when done in conjunction with RUDDER and THROTTLE tracking.
SRT_RDR = RUDDER error score when done in conjunction with STICK and THROTTLE tracking.
SRT_T = THROTTLE error score when done in conjunction with STICK and RUDDER tracking.

(7) HTDCC1 = Number correct in DIGIT CANCELLATION task when done in conjunction with HORIZONTAL TRACKING–First set of trials.
HTDC1 = HORIZONTAL TRACKING error scores when done in conjunction with DIGIT CANCELLATION task–First set of trials.
HTDCC2 Number correct in DIGIT CANCELLATION task when done in conjunction with HORIZONTAL TRACKING–Second set of trials.
HTDC2 = HORIZONTAL TRACKING error scores when done in conjunction with DIGIT CANCELLATION task–Second set of trials.
HTDCC3 = Number correct in DIGIT CANCELLATION task when done in conjunction with HORIZONTAL TRACKING–Third set of trials.
HTDC3 = HORIZONTAL TRACKING error scores when done in conjunction with DIGIT CANCELLATION task–Third set of trials.

(8) MN1_COR = Number correct in MANIKIN task–First set of trials.
MN1_INC = Number incorrect in MANIKIN task–First set of trials.
MN2_COR = Number correct in MANIKIN task–Second set of trials.
MN2_INC = Number incorrect in MANIKIN task–Second set of trials.
MN3_COR = Number correct in MANIKIN task–Third set of trials.
MN3_INC = Number incorrect in MANIKIN task–Third set of trials.
MN4_COR = Number correct in MANIKIN task–Fourth set of trials.
MN4_INC = Number incorrect in MANIKIN task–Fourth set of trials.

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13. ABSTRACT *(Maximum 200 words)*
The purpose of this study was to develop physical and selection performance standards for the screening of candidates for entrance into the Unmanned Aerial Vehicle (UAV) Pioneer Pilot training program. A minimum Pioneer crew consists of an external pilot, internal pilot, and a mission commander/payload specialist. The mission commander/payload specialist is responsible for the overall planning and execution of the specific mission and control of the visual/information gathering during the mission. The internal pilot is responsible for the control of the Pioneer when it is beyond visual range. The external pilot is responsible for take-offs, landings, and any in-visual-range control of the vehicle. A task analysis was done in the training and fleet squadrons to identify critical tasks for safe flight and the relevant skills required to perform the piloting tasks. From this task analysis, specific computer-based tests batteries were chosen as potential predictor variables. The system was programmed and students and external pilots were administered the test battery. A composite training measure was created from objective training scores, verified with subjective instructor ratings, and used as the criterion for predictive validation of the system. The sample size was small for the preliminary model, but a significant relationship between a composite of multitask tracking scores and UAV performance was observed (adjusted $R^2 = 0.86$). In addition, structured and unstructured interviews of the Pioneer crews, students, instructors and senior squadron personnel were used to identify important physical characteristics essential for safe operation of the Pioneer. These traits were then used to derive medical screening criteria for all crew positions.

14. SUBJECT TERMS
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